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CONCRETE INTEGRATED CONTAINER (CIC) PROGRAM
CONSTRUCTION OF 1/4 AND 1/8 SCALE MODELS

Report No. 88-97-K

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ABSTRACT

This report discusses the design, development and construction of two 1/4 scale and two 1/8 scale models of the Concrete Integrated Container (CIC). These models were subjected to drop tests from a 9 m height, and these tests comprised a joint effort between the Civil and Mechanical Research Departments investigating the scaled response of CIC models constructed in a 2 to 1 ratio (ie, 1/4 and 1/8 scale).

A high strength (40 MPa) and high density (3500 kg/m^3) concrete was developed for use in all four models, and the reinforcing for the models was simplified in order to meet constraints of material availability and construction tolerances. The models were cast on two different days, November 18, 1987 and February 8, 1988.

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CONCRETE INTEGRATED CONTAINER (CIC) PROGRAM
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J.A. Sato and H. Andre

1.0 INTRODUCTION

Since 1983, Ontario Hydro has been studying the use of concrete containers for storing, transporting and disposing of irradiated fuel/1,2/. In 1988, two prototype Concrete Integrated Containers (CIC) are to be constructed to demonstrate their irradiated fuel storage capabilities. A CIC of similar design may eventually be used to transport irradiated fuel, and as such, it will be required to undergo licensing tests conducted in accordance with International Atomic Energy Agency (IAEA) guidelines. In order to develop a licensing test program, the testing of scale models may be required. A joint effort was initiated between the Civil and Mechanical Research Departments to compare the response of 1/4 and 1/8 scale models, with simplified CIC geometry, subjected to a drop test of 9 m. The main purpose of these tests was to determine if the behaviour of models in the ratio of 2 to 1 is scalable (ie, repeatable). However, sufficient detail was provided in the models to generate design information on the overall response of the CIC to drop test impact conditions.

This report describes the work of the Concrete Technology Section, Civil Research Department, in the fabrication of the models.

2.0 DESCRIPTION OF MODELS

A total of four models, two 1/4 scale and two 1/8 scale, were constructed and tested. The models are made with high density reinforced concrete and have inner and outer steel liners, as shown in Figures 1 and 2. The models have exactly scaled overall dimensions of height, diameter, wall thickness, and liner thickness. Some elements of the CIC prototype design, however, had to be compromised in order to limit the complexity of the models. The models have a removable lid which is attached to the main body by a total of 16 lid bolts, as opposed to 32 lid bolts on the prototype CIC. The model bolts are correspondingly larger so that their net strength is actually about 25% greater than the prototype lid bolts. The lifting trunnions used for handling the prototype were also not modelled exactly, but rather were replaced by threaded rod anchored into the concrete side walls and bottom of the container at locations required for handling and alignment of the model in its drop

orientation. The reinforcement of the models is very similar to that of the prototype and is described further in Section 4.0. During the drop test, the models were equipped with impact limiters on both ends. A payload was placed inside the inner liner to simulate the irradiated fuel which will be stored and transported in the CIC. Both the impact limiters and the payload were designed by the Mechanical Research Department and will not be discussed in this report.

3.0 CONCRETE MATERIAL DEVELOPMENT

Previous research has shown that scale models require a concrete with the same compressive and tensile strength characteristics as the prototype/3/. The prototype CIC contains a high density concrete (ρ=3500 kg/m^3) using CSA Type 40 cement with a design strength of 40 MPa at 91 days/4/. A high density concrete was also used for the models; however, because it was not desirable to wait 91 days to achieve the required strength, Type 10 cement was substituted for the Type 40 cement used in the prototype. The use of Type 10 cement does not change any strength characteristics of the concrete, except to the extent that they are attained at an earlier age of 28 days.

In addition to similar strength characteristics, research has shown that the maximum aggregate size of the concrete must also be scaled in order to accurately model the bond and aggregate interlock characteristics/3/. The coarse aggregate used for the models is a high density screened material, with a maximum aggregate size of 5 mm, which is about 1/4 the maximum prototype coarse aggregate size. The same aggregate is used for the 1/8 scale model concrete, because to reduce the coarse aggregate size further would result in a concrete with a "mortar-like" consistency, which would affect its overall performance.

Three trial concrete mixes were tested to determine the optimum mix proportions for achieving the desired strength combined with the necessary workability to allow for easy placing of the concrete. The mix proportions for each trial, as well as their respective compressive strength development results are presented in Table 1. Table 1 indicates that the best 28-day compressive strength (38.1 MPa) was achieved for mix number 13854, and as such, this mix design was chosen for making the four models.

The strength results for the concrete actually used in constructing the models are discussed in Section 5.0.

4.0 REINFORCING STEEL AND ADDITIONAL HARDWARE

4.1 Design

In order to provide some information on the overall mechanical response of the prototype CIC under drop test conditions, it was necessary to model as many prototype details as feasibly possible. The spacing and size of the reinforcing bars in the prototype could not be scaled down exactly because of problems with availability of material and difficulty in construction. However, the reinforcing ratio for the hoop and longitudinal steel in the CIC walls was maintained at about 1.5%, which is consistent with the amount of prototype reinforcement. The reinforcing bar sizes were chosen to match the

smallest commercially available deformed steel, and the spacing was adjusted to provide the desired reinforcing ratios. In certain instances, such as for the lid and corner details, the reinforcement could not be duplicated exactly due to problems associated with fabrication and steel congestion leading to difficulties in placing of the concrete. It was agreed, however, that the simplifications made were generally consistent with the intent of the prototype reinforcing/5/. Figures 3 and 4 show the reinforcing details for the 1/4 and 1/8 scale models.

The lid bolts and lifting trunnions of the prototype CIC could also not be exactly modelled because of availability of materials, and the difficulty of fabrication. The model lid bolts and lifting anchors were chosen on the basis of ensuring adequate strength to limit failure of these components.

4.2 Material

The reinforcing steel used in the models was a deformed fabric wire for the main steel (hoops and longitudinal bars), and smooth cold-rolled steel wire for the ties (SAE/AISI No. 1010). The main steel was 9.9 mm and 5.0 mm in diameter for the 1/4 scale and 1/8 scale models, respectively. Deformed fabric wire, which is a cold drawn steel wire with indentations along its surface to provide bond, was used because ordinary reinforcing steel is not available in the small sizes required. Deformed fabric wire is produced to Canadian Standard CSA G30.14, and has a nominal yield stress of 485 MPa, minimum, and an ultimate tensile strength of 550 MPa, minimum. There is no distinct yield plateau for this steel, which results in its stress-strain response being significantly stiffer than that of ordinary reinforcing steel at strains greater than yield/5/.

The lid bolts and lifting anchors were made from 15.9 mm (5/8") and 7.9 mm (5/16") diameter high strength alloy steel threaded rod and matching high strength nuts, for the 1/4 and 1/8 scale models respectively. This rod conformed to ASTM A-193 B7 and had a minimum tensile strength of 830 MPa.

5.0 MODEL CONSTRUCTION - FABRICATION AND CASTING

The fabrication of the models consisted of assembling the reinforcing cages (Figure 5) and then aligning each between the inner and outer steel liners, which acted as formwork. Figure 5 is a photo of the reinforcing cage for a 1/8 scale model being assembled, and in Figure 6 the main body reinforcing cages for a 1/4 and 1/8 scale model and their respective lid reinforcing cages are shown. Figure 7 shows a 1/4 scale model body fully prepared for casting. Since each model was cast in an inverted position, to avoid air voids from forming under the inner liner, the open end of the steel can was actually the bottom of the model. Also seen in Figure 7 are threaded rods protruding from the side and bottom of the model which were used as lifting trunnions for hoisting and aligning the model for the drop test. The lids for all the models were also cast in an inverted position.

The concrete was batched and placed at the concrete laboratory in the Civil Research Department. The concrete in the 1/4 scale model was consolidated using a 3/4" diameter vibrator (Figure 8), while the concrete in the 1/8 scale model and all the lids was consolidated on a vibrating table. The inner and

outer steel liners acted as the formwork and no additional bracing was required. The bottom steel liner plates for the main body and lids were set in place after the concrete was placed in order to provide a closed environment for curing. After the concrete had cured for one week, at which point the compressive strength was in excess of 30 MPa, the bottom plates were then welded in place. Concrete cylinders were cast and cured alongside the models for determining the concrete properties (see Table 2 for the hardened concrete properties).

Two 1/8 scale models and one 1/4 scale model were cast on November 18, 1987, and tested on January 11 and 13, 1988. The casting of the other 1/4 scale model was delayed until February 8, 1988 due to defects in fabrication of the steel can. This model was drop tested on April 22, 1988.

6.0 SUMMARY

A joint program between the Civil and Mechanical Research Departments investigating the response of 1/4 and 1/8 scale Concrete Integrated Container (CIC) models subjected to a 9 m drop test was undertaken. The purpose of this program was to determine if the behaviour of CIC models in the ratio of 2 to 1 is scalable. The principal responsibilities of the Civil Research Department were to develop the "scaled" concrete to be used in the models, design simplified reinforcing, and to construct and cast all models. In this regard:

(a) The concrete that was developed used high density aggregate with a maximum coarse aggregate size of 5 mm, Type 10 cement, and a superplasticizing admixture to attain a hardened density in excess of 3500 kg/m^3 and a 28-day compressive strength of 40 MPa. This concrete was used in both the 1/4 and 1/8 scale models.

(b) The reinforcing for the CIC models had to be simplified due to problems with availability of materials and practical difficulties in construction. For example, the smallest commercially available deformed steel was utilized (with necessary adjustments to the reinforcing spacing to maintain the prototype CIC reinforcing ratios) and in certain instances (ie, corner and lid details), the arrangement of the reinforcing steel could not be exactly duplicated due to problems with fabrication and placement of concrete. However, it was agreed that the simplifications were generally consistent with the intent of the prototype reinforcing.

(c) Two 1/8 scale and one 1/4 scale models were cast on November 18, 1987 and the second 1/4 scale model was cast on February 8, 1988.

7.0 ACKNOWLEDEMENTS

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TABLE 1

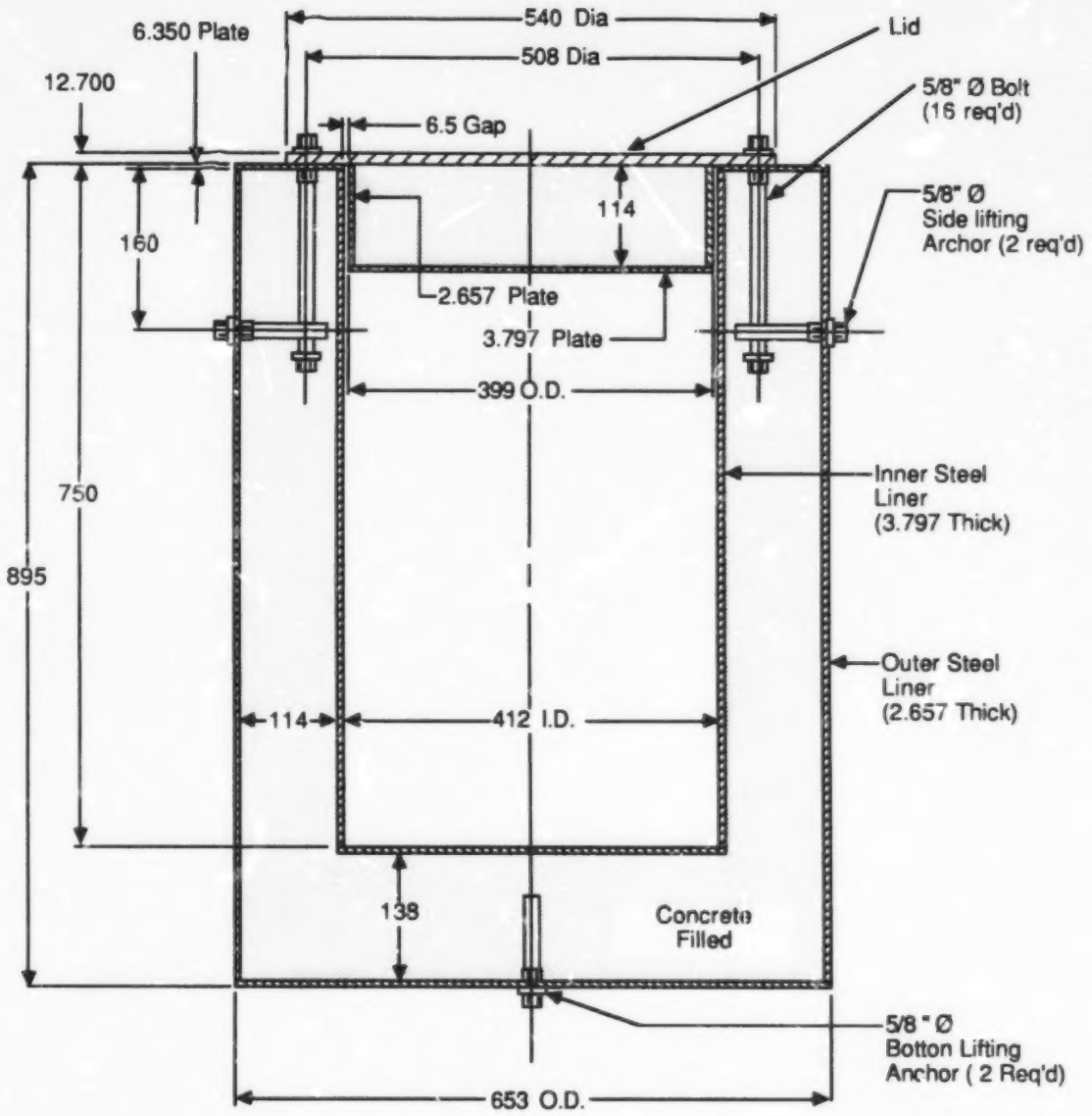
CIC MODEL CONCRETE TRIALS

Mix Number	Cement	Mix Proportions (kg/m^3)		Water	Admixture (ml/kg CEM.)	W/C	Hard Density (kg/m^3)	Compressive Strength (MPa)		
		Fine Agg	Coarse Agg					3-Day	7-Day	28-Day
13850*	400	1250	1750	146	44	0.36	3614	18.1	23.4	31.2
13853**	425	1190	1800	196	15	0.46	3563	26.7	28.6	34.6
13854**	500	1100	1800	205	15	0.41	3533	29.8	30.7	38.1

W/C = water-to-cement ratio
Materials: Cement - * Type 40, ** Type 10
Fine Aggregate - High density specularite
Coarse Aggregate - High density coarse screening, "PL4"
Admixture - * Mighty 150, ** Melment L-10

TABLE 2
Concrete Properties

	Casting of Nov 18/87		Casting of Feb 8/88	
	28-day	Day of Test	28-day	Day of Test
Compressive strength (MPa)	42.9	45.3	41.2	44.8
Split tensile strength (MPa)	-	4.3	3.8	4.0
Modulus of Elasticity (MPa)	46,340	46,920	45,785	45,800
Density (kg/m^3)	-	3533	-	3536



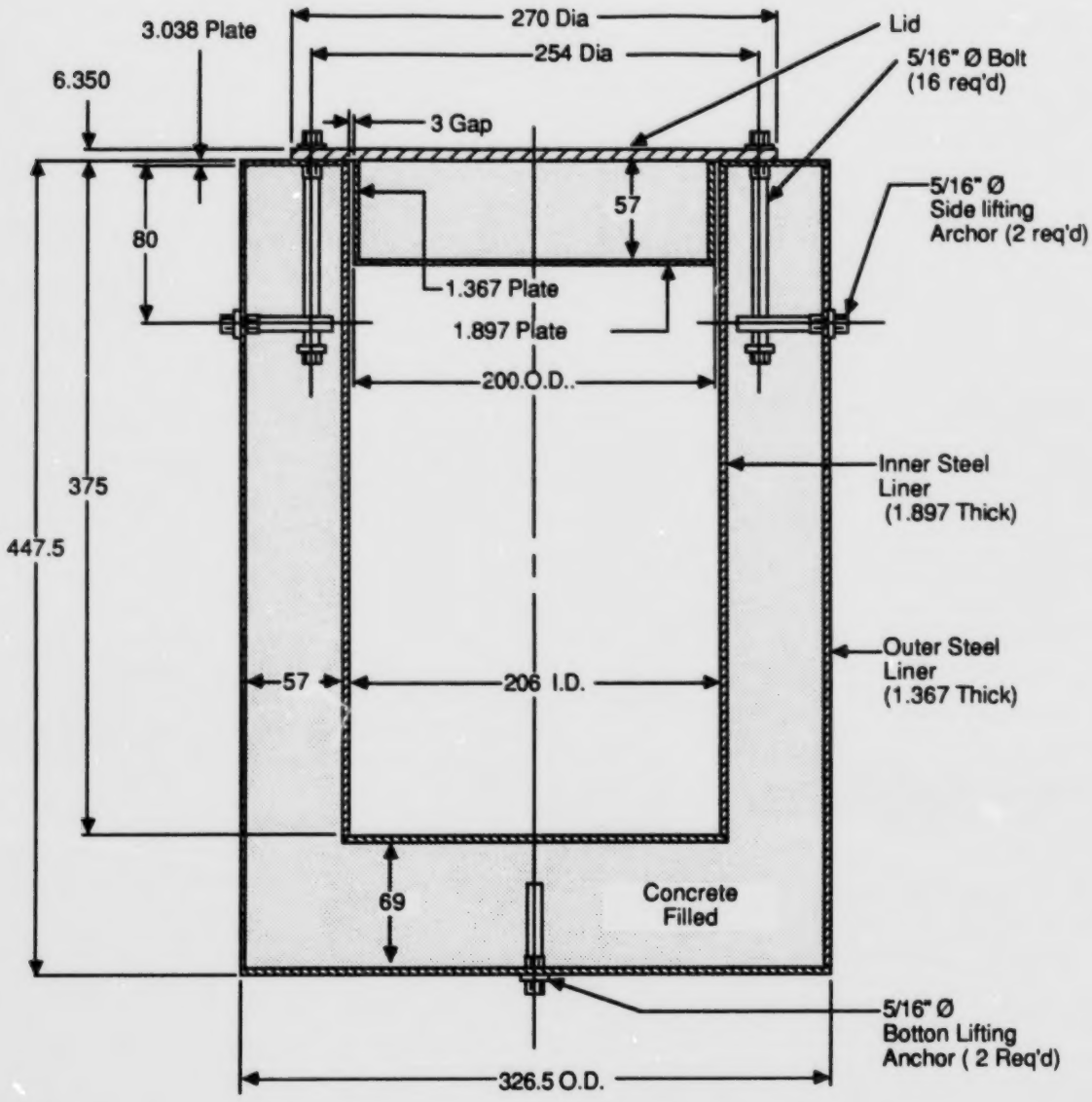
Notes:

1. All dimensions are in mm (unless otherwise noted)
2. Concrete density is 3500 kg/m^3 minimum, with a 28 day strength of 40 MPa
3. Steel plate: CSA G40. 21M, 300WT

FIGURE 1
1/4 SCALE MODEL DIMENSIONS

88-97

176605-RD
knarf 3 disk



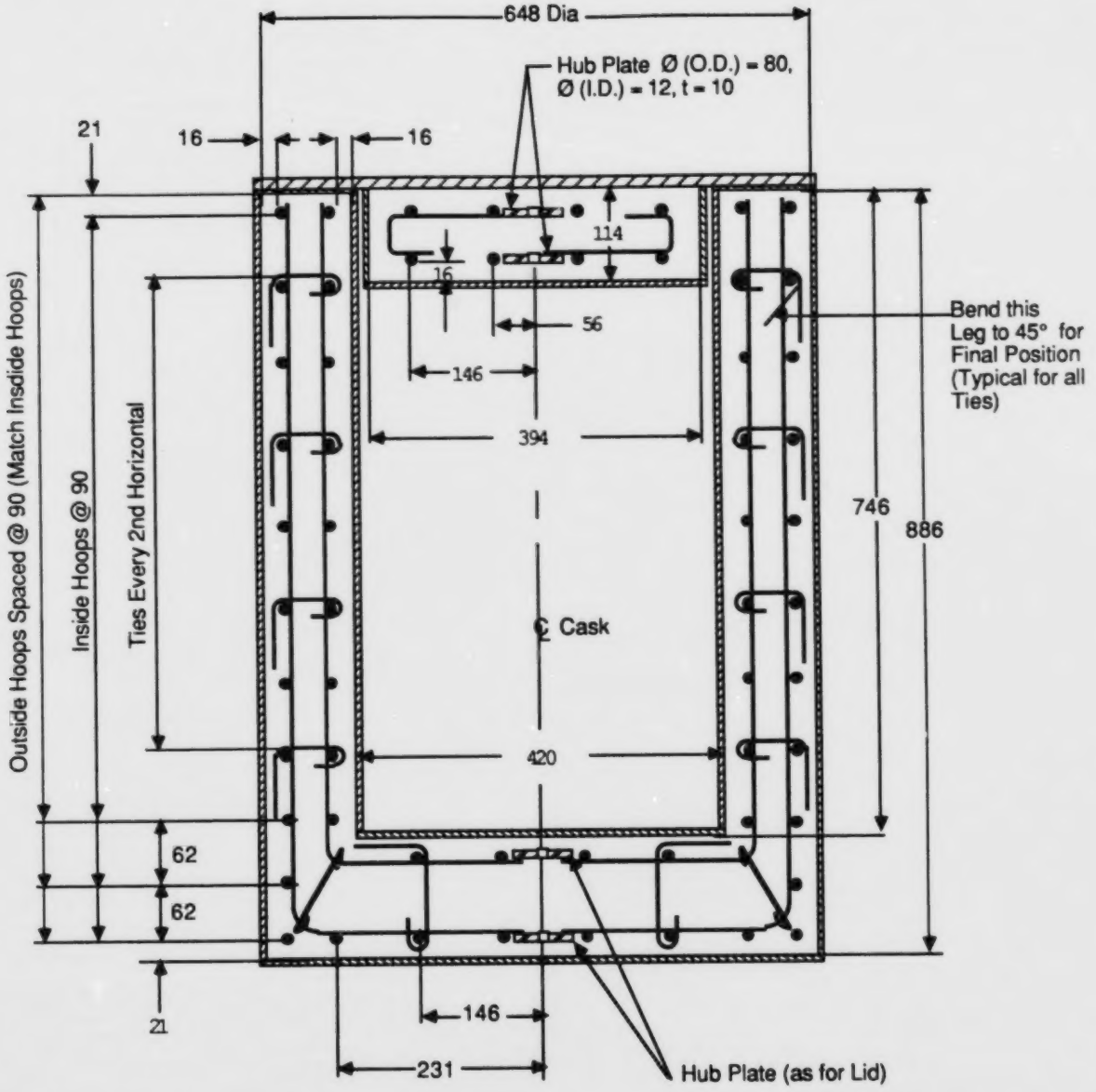
Notes:

1. All dimensions are in mm (unless otherwise noted)
2. Concrete density is 3500 kg/m^3 minimum, with a 28 day strength of 40 MPa
3. Steel plate: CSA G40. 21M, 300WT

FIGURE 2
1/8 SCALE MODEL DIMENSIONS

88-97

176606-RD
knarf 3 disk



Note: All dimensions are in mm

FIGURE 3

1/4 SCALE MODEL - TYPICAL REINFORCING DETAILS

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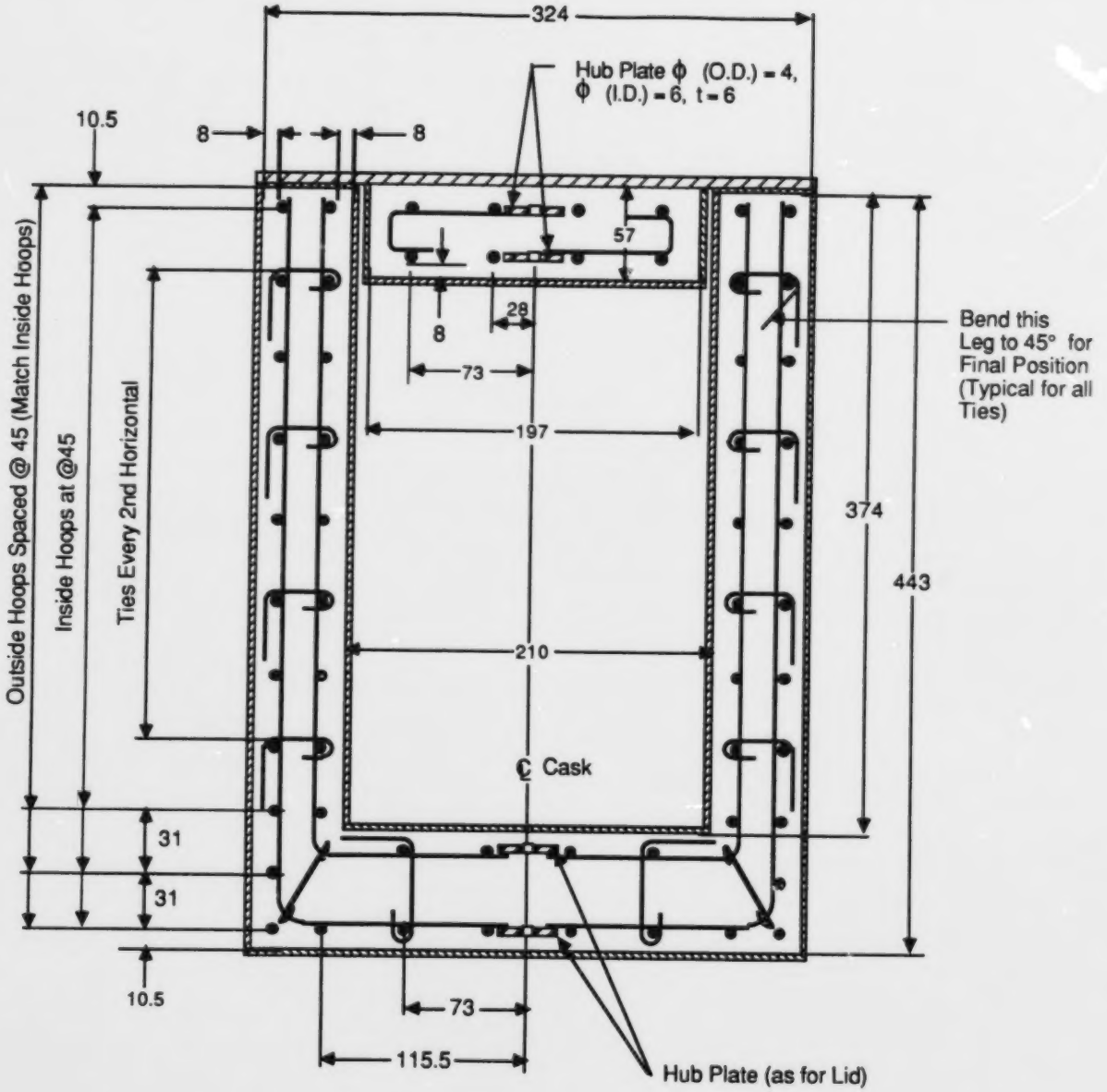
176607-RD

KNARF 3 DISK



Note: All dimensions are in mm

FIGURE 4

1/8 SCALE MODEL - TYPICAL REINFORCING DETAILS

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176608-RD
KNARF 3 DISK

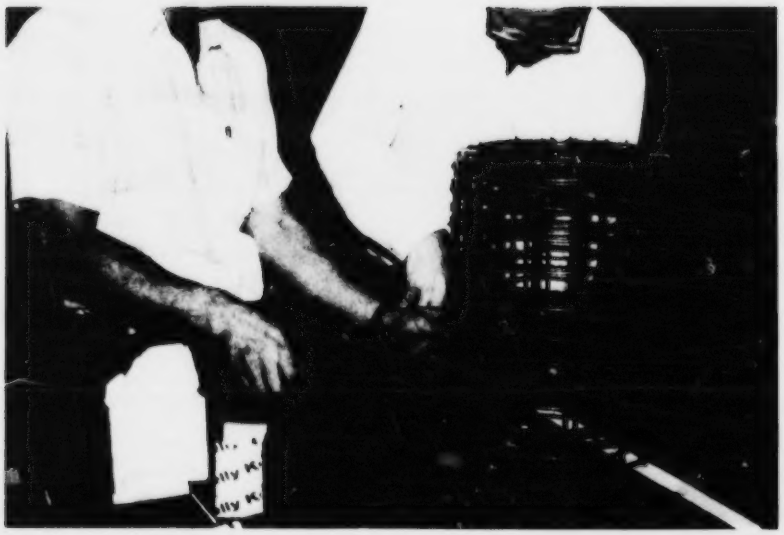

FIGURE 5

ASSEMBLING A 1/8 SCALE MODEL REINFORCING CAGE

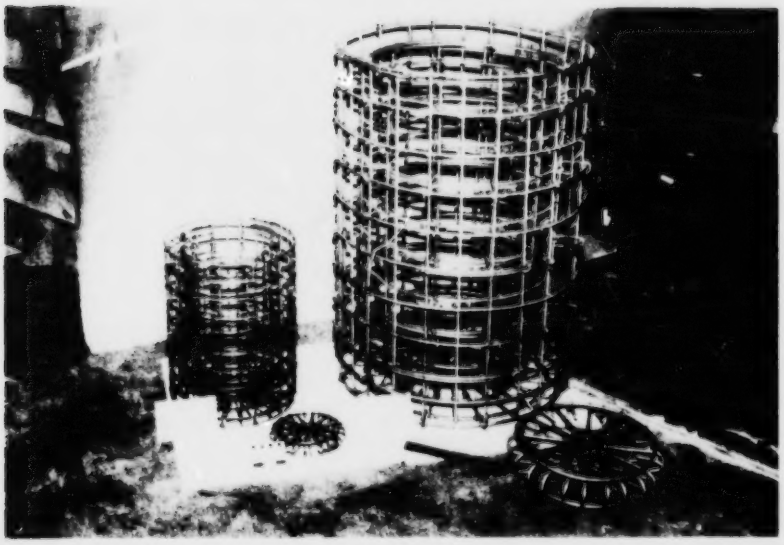

FIGURE 6

BODY AND LID REINFORCING CAGES FOR 1/4 AND 1/8 SCALE MODELS

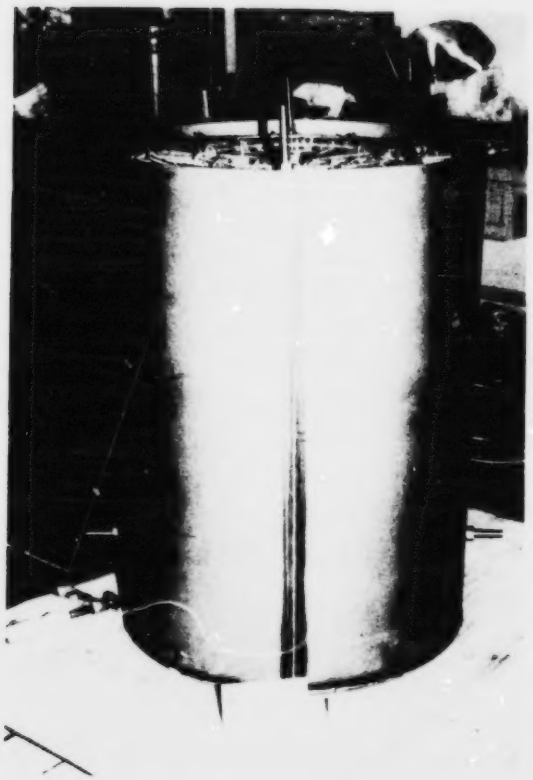

FIGURE 7

1/4 SCALE MODEL BODY PREPARED FOR CASTING (MODEL IS IN INVERTED POSITION)

FIGURE 8

CASTING THE 1/4 SCALE MODEL